

# RATCHETTING OF COMPOSITE PIPES

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This study is especially dedicated to my beloved Mommy and Daddy  
Brothers and Sisters,  
Beloved wife,  
*Norhayati Nor Hakimi*  
for everlasting love, care, and supports.....

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## ABSTRACT

The uniaxial ratchetting characteristics of fibre glass reinforced epoxy laminate have been investigated in the present project. The specimens were subjected to cyclic axial stress with a constant mean stress of 40 MPa and a varying amplitude stress of 26.67 MPa and 53.33 MPa. Tests were also performed on 50 mm diameter, Glass fibre Reinforced Epoxy (GRE) straight pipe. The pipe was subjected to a constant internal pressure of 1.875 MPa and a cyclic axial load. The finite element model in ABAQUS has also been simulated in similar loading case. The comparisons between experiment and simulation results were observed. The effect of fibre orientation on the rate of ratchetting was also investigated at the present project. The uniaxial and biaxial ratchetting strain was observed to increase with a number of cycles but decreased the rate of ratchetting. The specimen showed no further ratchetting rate and exhibited shakedown after some strain accumulation. On the basis of experiment and simulation, it appears that ratchetting would occur in the circumferential direction for a composite pipe subjected to constant internal pressure and cyclic displacement with no ratchetting observed in axial direction. A direction in fibre orientation seemed to have effect on the rate of ratchetting. Thus, the increasing of fibre angle from the axial load axis will increase the rate of ratchetting.

## ABSTRAK

Perilaku ratchetting satu paksi ke atas laminat *fibre glass reinforced epoxy* telah dikaji dalam projek ini. Spesimen ini dikenakan tegasan paksi berkisar pada tegasan min malar 40 MPa dan tegasan amplitud 26.67 MPa dan 53.33 MPa. Ujian ke atas paip lurus jenis *Glassfiber Reinforced Epoxy (GRE)* berdiameter 50 mm turut dijalankan. Paip ini telah dikenakan tekanan dalaman 1.875 MPa secara malar dan kitaran terikan paksi. Simulasi kaedah unsur tak terhingga menggunakan ABAQUS juga telah dilakukan dengan aplikasi beban yang sama. Perbandingan keputusan daripada eksperimen-eksperimen dan simulasi-simulasi turut dianalisis. Kesan arah orientasi fiber ke atas kadar ratchetting juga dikaji dalam projek ini. Terikan ratchetting sepaksi dan dwipaksi menunjukkan pertambahan dengan bilangan kitaran tetapi kadar ratchetting berkurang. Spesimen menunjukkan tiada lanjutan ratchetting dan berlaku shakedown selepas beberapa pengumpulan terikan. Berdasarkan eksperimen dan simulasi, ia menunjukkan ratchetting hanya berlaku dalam arah lilitan paip komposit tersebut apabila dikenakan tekanan dalaman secara malar dan kitaran terikan paksi dengan tiada ratchetting berlaku dalam arah paksi paip. Arah dalam orientasi fiber juga memberi kesan ke atas kadar ratchetting. Pertambahan sudut fiber dari paksi arah beban akan meningkatkan kadar ratchetting.

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## NOMENCLATURE

<u>SYMBOL</u>	<u>DEFINITION</u>
$S_m$	mean stress
$\sigma$	stress tensor
$\sigma_0$	size of the yield surface
$\alpha$	center of the yield surface
$S$	deviatoric stress tensor
$a$	center of the yield surface in the deviatoric space
$H$	plastic modulus
$P_{ij}$	spherical stress tensor
$\sigma_m$	hydrostatic stress
$e_m$	corresponding volumetric strain
$d\lambda$	instantaneous non-negative constant
$\varepsilon^p$	plastic strain
$\varepsilon^R$	ratchet strain
$d\varepsilon^e$	elastic strain increment
$d\varepsilon^p$	plastic strain increment
$d\varepsilon^T$	total strain increment
$\sigma$	stress
$\sigma_y$	yield stress
$\sigma_e$	equivalent stress
$d\varepsilon_p$	equivalent plastic strain increment
$n$	$\sigma_y / \sigma_\theta$

$E$	Young modulus
$\nu$	Poisson ratio
$d$	cylinder diameter
$t$	wall thickness
$p$	pressure
$W$	load

SUBSCRIPTSDEFINITION

$R$	radial direction
$\theta$	hoop direction
$\phi$	axial direction



## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Piping networks are often employed in various industrial applications. Generally, piping systems in heavy industries such as power plants, offshore platforms, marines etc. are designed for normal operation loads (pressure) along with cyclic loads, such as earthquake. Cyclic excursions into the plastic range can lead to degradation and failure of such piping due to accumulation of deformation. The strain accumulation induced by cyclic loading is called ratchetting. Ratchetting can be either due to thermal processes or due to mechanical cyclic loading. In the present project, however, only mechanical ratchetting has been investigated.

Prevention of ratchetting is a difficult problem in the design of a component subjected to cyclic loads that may lead to inelastic deformation. During such loading, material and structural aspects interact. Large deformation of a piping system is possible under combination of primary (constant) and secondary (cyclic) loads. In such a case, a small amount of plastic strain, which is not reversed in each cycle, may lead to unacceptably large accumulated strain.

## 1.2 Problem of Interest

There are numerous studies on ratchetting behaviour. In the last two decades, uniaxial and biaxial ratchetting behaviours were studied experimentally and theoretically by some researchers, as reviewed by Ohno (1997), Bari and Hassan (2002) and Abdel-Karim (2005) and recently done by Chen et al. (2004), Kang et al. (2004), Feaugas and Gaudin (2004), Mayama et al. (2004), Vincent et al. (2004), Abdel-Karim (2005), Gupta et al. (2005), Johansson et al. (2005), Khoei and Jamali (2005), Yaguchi and Takahashi (2005) and so on. The existing results showed that the ratchetting varies depending on the material type. Based on the Armstrong–Frederick non-linear kinematic hardening rule (1996), many constitutive models have been constructed to simulate the uniaxial and biaxial ratchetting. Examples of these models have been created by Chaboche and Nouailhas (1989), Ohno and Wang (1993), Chaboche (1994), Delobelle et al. (1995), Jiang and Sehitoglu (1994), Abdel-Karim and Ohno (2000), Kang et al. (2002), Gao et al. (2003), Vincent et al. (2004), Yaguchi and Takahashi (2005), Chen et al. (2004) and so on. The above-referred works were only focused on the ratchetting behaviour and its constitutive model on metallic material.

Ratchetting behaviour has also been observed in polymer materials, such as epoxy resin and Chen and Hui (2005) conducted series tests to study the ratchetting behaviour of PTFE under cyclic compression load, where the effects of loading rate, mean stress and stress amplitude on the ratchetting behaviour were discussed.

However, researches on ratchetting behaviour of composite materials are still relatively few. More investigations are necessary for in-depth understanding of the ratchetting phenomenon of these materials. More recently, composite pipes has further gained its importance in the offshore oil and gas industry due to its light-weight, corrosion resistance, and the new invention of Tension Leg Platforms (TLPs) for deep-water oil and gas exploration and production. Since the composite pipe is very important in the design and assessment of structure components, it is necessary to examine the ratchetting response of composite pipe. In order to understand the ratchetting behaviour

for composite pipe, an experimental and simulation study was performed based on the similar experiment set-up for metallic material which already investigated previously.

### **1.3 Research Objectives**

The objectives of this research project are:

- a) To derive the mathematical model for ratchetting rate of metallic material.
- b) To obtain the ratchetting rate of metallic material using finite element program (ABAQUS).
- c) To investigate the ratchetting behaviour of fibre glass reinforced epoxy plate and pipe experimentally.
- d) Validate the experiment results with finite element program (ABAQUS).
- e) To investigate the effect of fibre direction to ratchetting rate of composite materials.

### **1.4 Scope of Research**

In this work, the main objective is to investigate the ratchetting behaviour of fibre glass reinforced epoxy. First, the dependence of the ratchetting of metallic materials on mean stress, stress amplitude and stress ratio are observed. When the ratchetting response of a metallic material is sufficiently understood and simulated, the ratchetting of the fibre glass reinforced epoxy are investigated in similar loading cases by performing a systematic experiment and simulation. Then, the verification between experiment and finite element simulation is discussed in detail. Finally, the effect of fibre direction to ratchetting rate of composite material is investigated.